WFA Test Plan Considerations and Recommendations

WFA LTE-U/Wi-Fi Coexistence Test Plan

- A lot of effort has been spent in shaping and verifying the test plan, and Qualcomm has actively contributed to every step of the process including lab validation

- Qualcomm has consistently raised issues on fundamental test plan topics:
  - Need for simplification, to ensure focus on important topics
  - *Energy levels at which coexistence is tested, and applicability thereof*
  - *Need for a fair, correct and complete WiFi baseline*
  - *The presence of unnecessary, unprecedented and unmotivated requirements for in-device coexistence.*

- *Qualcomm has consistently raised these concerns via active participation and submissions, as well as active testing and verification in WFA and Qualcomm labs*
  - *Concerns are pragmatic, long-standing, and line with test observations and concerns, as well as real-world geometries*
  - *Also addressed in the latest suite of comments (over 30) to test plan 0.8.4*

Most of the fundamental concerns raised in our comments remain unaddressed although many of them was to simplify the execution and repeatability of the test plan

WFA LTE-U/Wi-Fi Coexistence Test Plan

- Scope of the test plan has been on testing and validating the test plan for non-LBT LTE-U equipment
  - The coexistence test plan text scope should explicitly capture that it is only applicable to equipment that do not follow Listen-Before-Talk as defined in 3GPP Rel13 or ETSI standard EN 301 893 (LAA and 802.11ax)

WFA LTE-U/Wi-Fi Coexistence Test Plan

- Test Level 3
  - Wi-Fi only backs off to other technologies at -62dBm
  - Field measurements presented and Wi-Fi vendors guidelines available online confirm that RSSI distribution in managed indoor deployments are typically higher than -65dBm with high SINR (20-30dB)
  - We proposed that non-LBT equipment designated for indoor use only should be tested at levels 1 and 2 only (-50dBm, -67dBm), while non-LBT equipment designated for outdoor can be tested at all 3 levels (-50dBm, -67dBm, -82dBm)

- Our proposal in essence means that LTE-U is **10 times** more polite than Wi-Fi to other technologies in indoor, and **100 times** more polite than Wi-Fi in outdoor environments
- Latest released v0.8.6 applies -82dBm for indoor equipment and testing is done at 0dB SINR
  - Contradicts with existing field data and common sense

WFA LTE-U/Wi-Fi Coexistence Test Plan

- Test plan v.0.8.6 lacks a definition of inter-vendor baseline Wi-Fi which should be reference for pass/fail criteria
- QC proposed an inter-vendor Wi-Fi baseline test, which was discussed in the TG weekly meeting, and QC modified the inter-vendor baseline test based on technical comments from the meeting
  - WFA Staff did not adopt this proposal in the released test plan on the basis of longer timeline, which contradicts not adopting the procedure simplifications that were proposed
- The test plan is assuming specially configured single Wi-Fi vendor with a mode that does not reflect commercial reality
  - which does not represent real world out of the box Wi-Fi equipment, nor is it fair to LTE-U as it lacks inter-vendor Wi-Fi testing
  - As it stands, WFA Test Plan requires LTE-U to be more fair to Wi-Fi than other Wi-Fi
- The inter-vendor baseline is the only way to define pass/fail criteria for LTE-U, otherwise the **test plan is fundamentally biased and unfair**

WFA LTE-U/Wi-Fi Coexistence Test Plan

- In-device coexistence is not unique to LTE-U/Wi-Fi, as the problem occurs in other scenarios
  - Wi-Fi/BT
  - LTE in B40/B7 and Wi-Fi
- Given LTE-U is downlink only, the interference is from Wi-Fi to LTE-U, not the other way
- 3GPP defined optional signaling to solve in-device problem, but there are more effective proprietary solutions to solve this problem
- In-device coexistence is out of scope of the WFA test plan which is defining sharing with other Wi-Fi devices
- *We recommended to remove Test case 4.6 on in-device coexistence from the WFA test plan as it is out of scope and many companies agreed to this*

Despite the above, WFA staff not only kept the test case, but the latest test plan makes an optional feature in 3GPP MANDATORY to pass the WFA test plan!

Summary

- We are concerned about the fairness of the test spec development process
- The scope of the current test plan needs to be specified clearly
  - The test scope should have an explicit statement that it is only for non-LBT devices and not applicable to LBT-based devices
- The current WFA Test Plan contradicts the principal of using field data to decide test levels
  - E.g.: should not be using -82dBm for indoor equipment
- The current WFA Test Plan requires LTE-U to protect Wi-Fi more than Wi-Fi
  - There needs to be an inter-vendor Wi-Fi baseline for the relevant test cases
- The in-device test is out of the scope of the test plan
  - The test plan should focus on LTE-U coexistence with other Wi-Fi devices, and not force an irrelevant in-device implementation

The WFA test plan as stands now is biased and lacks technical merit for establishing fair sharing

BACKUP

Test Plan Verification: Illustrated Issues

Introduction

- Verification remains elusive for important test plan cases
  - No independent mechanism for recognizing failure of non-DUT or baseline nodes (4.2-4.5).
  - Synthetic baseline, irrelevant to real-world experience (4.2, 4.4).
  - Absence of baseline characterization for the test plan (4.2 - 4.5)
  - Non-deterministic Pass/Fail criteria (4.3, 4.5)

- e.g. Test Case 4.4 (VoWiFi performance)
  - Significant proportion of W+W runs found to experience failure of non-DUT or baseline WiFi nodes, ranging from connectivity issues, to unexpected KPIs, significantly overwhelming test-plan criteria.
  - Significant KPI variance run-to-run due to Passive Scanning

- e.g Test Case 4.5 (Throughput Verification)
  - Very wide range of throughputs in W+W coexistence.
  - Single-vendor baseline opens up test to pass-fail criteria randomness.

Test Plan Verification: Illustrated Issues

Test case 4.5 (Throughput Verification)

4.5: Throughput Verification

- Test Case 4.5 intends a throughput criterion

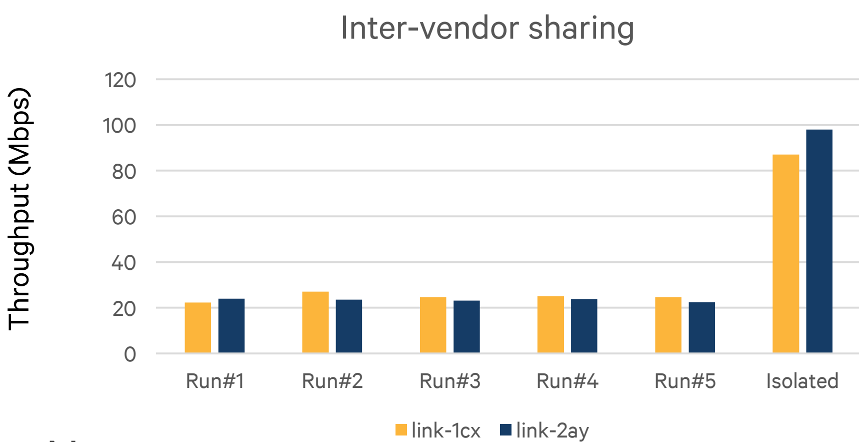
- An multi-sample inter-vendor baseline was proposed, to arrive at a reasonable pass-fail criterion
  - LTE-U / WiFi CoExistence resembles an inter-vendor test case
  - C.f. "Test Plan: Baseline Testing and Simplifications Proposal"

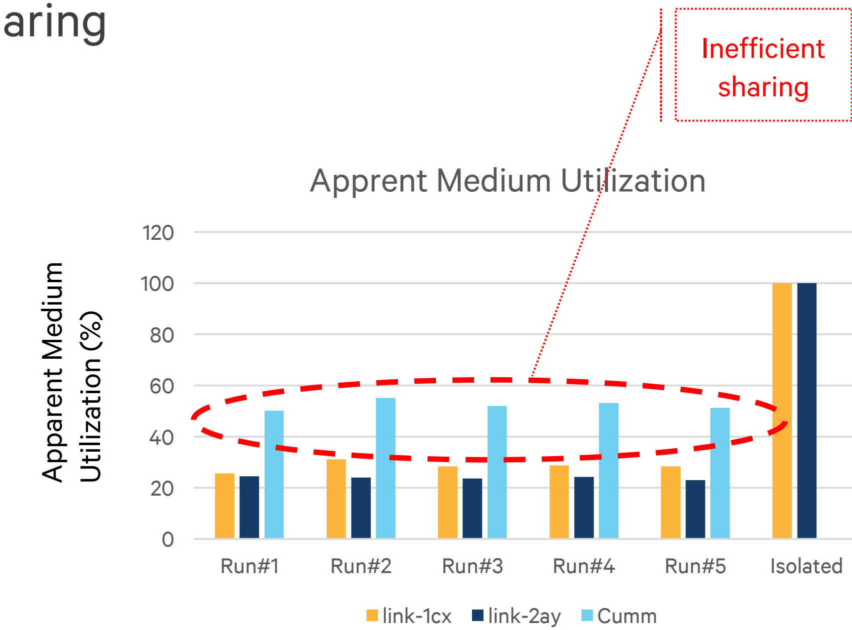
- WFA Staff indicated preference to avoid an inter-vendor baseline, for "pragmatic" considerations.

- Limiting the baselining effort to a reference intra-vendor WiFi + WiFi combination leaves a lot of entropy in the ultimate pass criterion
  - Idealized medium sharing is far from realized in practice
    - a very wide distribution of WiFi vs WiFi throughput performance, across intra- and inter-vendor samples.
  - An intra-vendor baseline would give a false impression that a reasonable criterion is being specified.

4.5: Illustration of WiFi + WiFi coexistence (inter-vendor)

- Inter-vendor coexistence: unfair medium sharing
  - WiFi link1ax: AP-A + STA_X
  - WiFi link2cy: AP-C + STA_Y

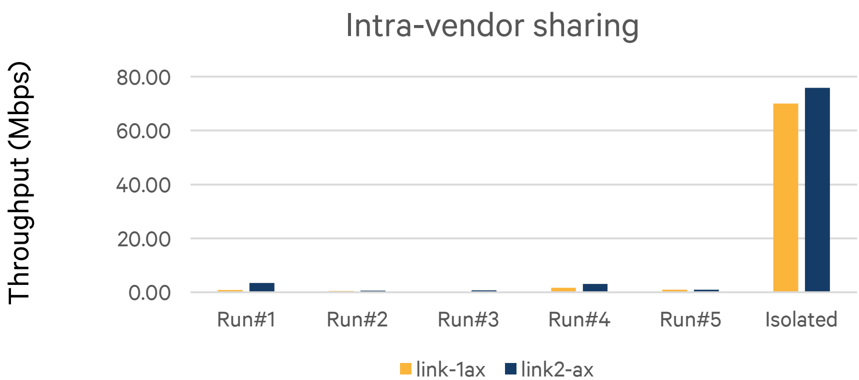


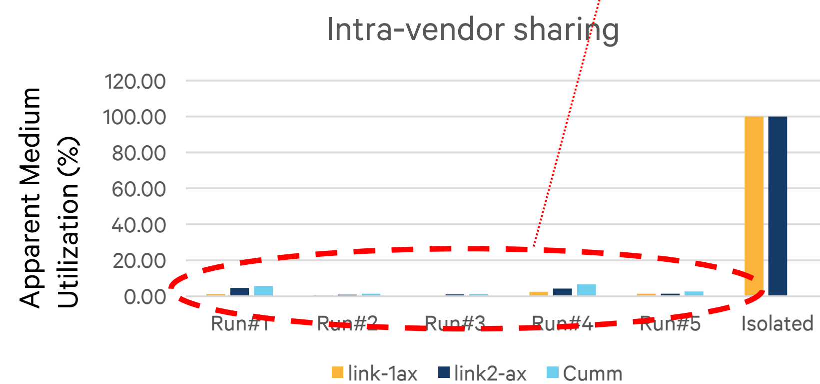


- Notes:
  - **Apparent medium utilization** of link X
    - = (link X throughput)$_{\text{W:X +W:Y CoExistence}}$ / (link X throughput)$_{\text{W:X Standalone}}$
    - Intuitively measures the medium ratio used by link X when coexisting (ideally TDD-ing) with another link Y
  - **Cumulative apparent medium utilization** when links X and Y coexist:
    - = (Apparent medium utilization of link X) + (Apparent medium utilization of link Y)
  - AP-A and STA_X are “latest-models” of WiFi nodes used in the WFA lab. AP_C is a WiFi node model used in the WFA lab. STA_Y is a popular “latest-model” WiFi node.
  - All test cases were run at test level-2, with AP-STA RSSI of -70 dBm

4.5: Illustration of WiFi + WiFi coexistence (intra-vendor)

- Intra-vendor coexistence shows non-ideal behavior
  - WiFi link1a: AP-A + STA_X
  - WiFi link2a: AP-A + STA_X





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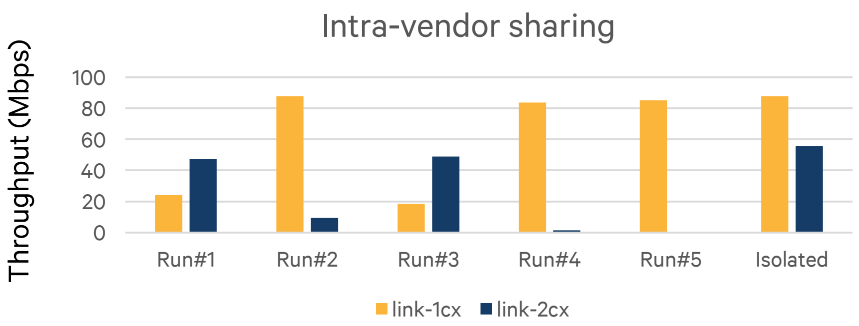

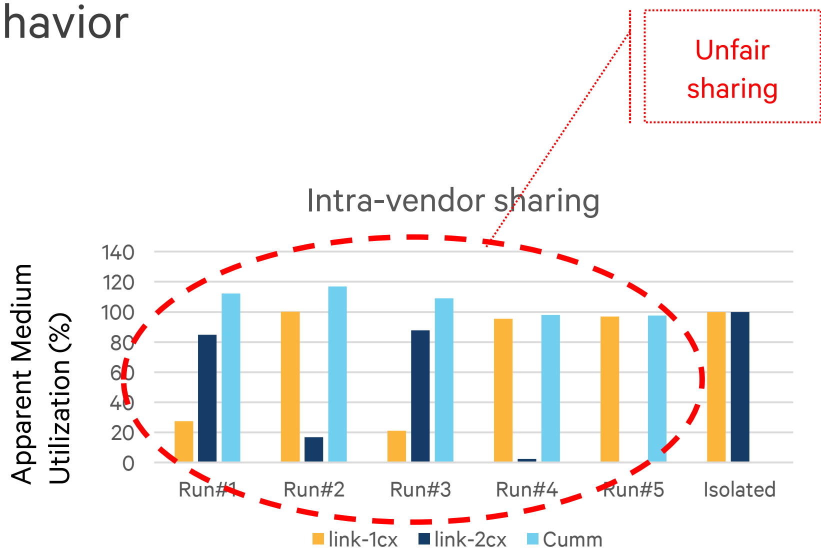

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  - **Cumulative apparent medium utilization** when links X and Y coexist:
    - = (Apparent medium utilization of link X) + (Apparent medium utilization of link Y)
  - AP-C is a model used in the WFA lab
  - STA_X is a “latest-model” of a WiFi node used in the WFA lab
  - All test cases were run at test level-2, with AP-STA RSSI of -70 dBm

4.5: Summary of observations

- The throughput achieved by any one WiFi node is far from representative of the distribution of W + W throughput sharing results
- Factors influencing outcome:
  - Four-tuple composing the WiFi node modes being tested
    - combinations of AP_A, AP_C, STA_X, STA_Y
  - The particular channel realization (RSSI is not a sufficient indicator of channel)
  - Non-ergodic behavior of WiFi nodes

- Test case verification
  - A legitimate throughput criterion for WiFi Coexistence test case must be passed by a WiFi node as well. This was the reason for using inter-vendor baseline
  - **Any one reference WiFi AP/STA combination selected for the 4.5 test case will necessarily be irrelevant to establishing a legitimate baseline.**

- Relation to Test Case 4.3
  - Focus above is on issues pertaining to medium sharing by two links
  - Concerns also apply to medium sharing by multiple links would increase exponentially with the number of sharing links (some cases have 10 links).
  - WFA has not even started looking into throughput verification for test case 4.3 …
  - Recommending to limit test case 4.3 to medium utilization verification

Test Plan Verification: Illustrated Issues

Test case 4.4 (VoWiFi KPI verification)

4.4: VoWiFi KPI Verification

- Test Case 4.4 verifies VoWiFi KPIs (latency, jitter, loss)

- Significant proportion of W+W runs found to experience failure of non-DUT or baseline WiFi nodes, ranging from connectivity issues, to unexpected KPIs, significantly overwhelming test-plan criteria.
  - Unclear how to independently distinguish between WiFi node failures and legitimate baseline behavior. No WFA procedure in place to distringuish

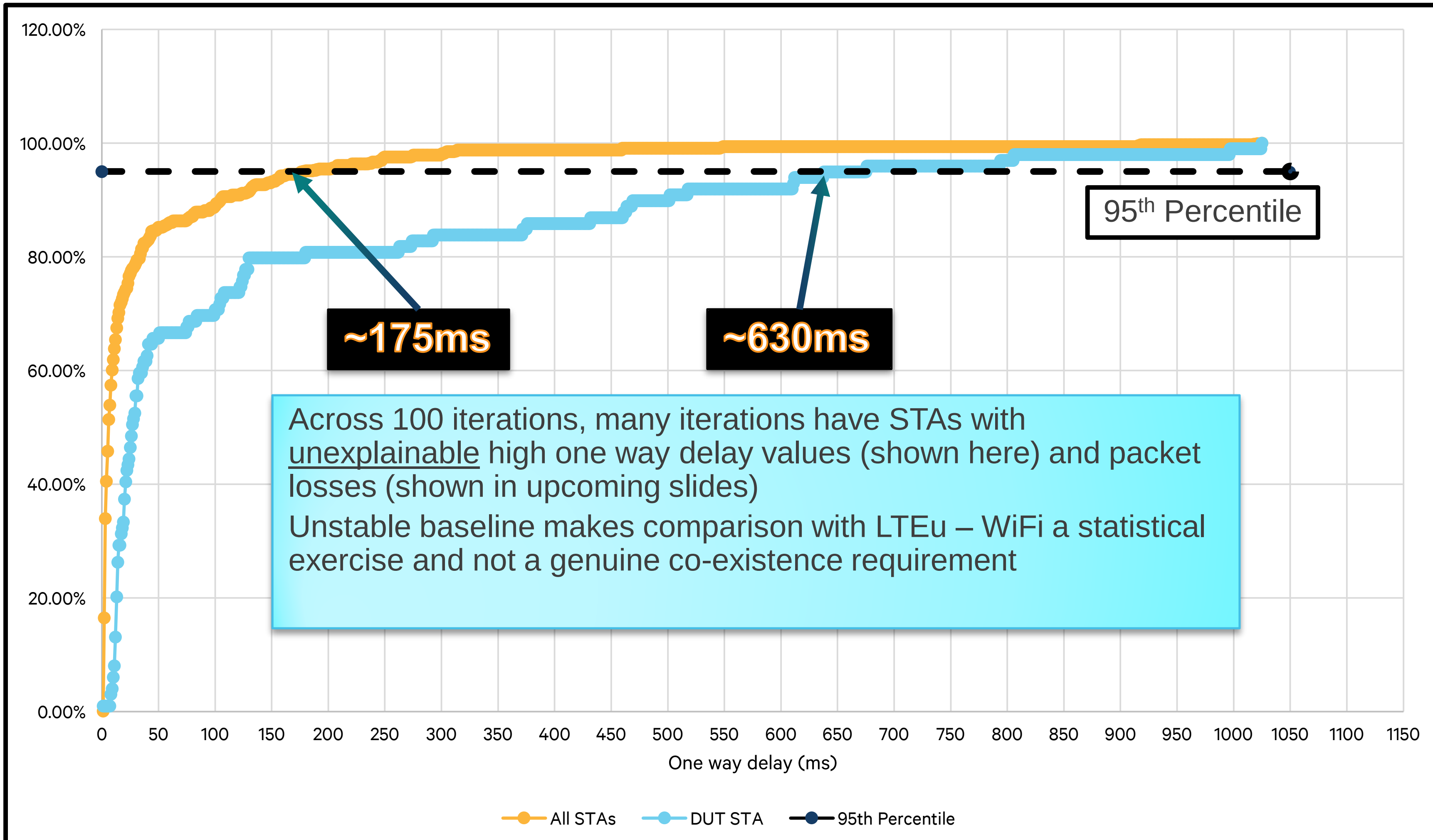
- Significant KPI variance run-to-run due to Passive Scanning
  - Basic issue is this test case is at RSSIs that trigger passive scanning.
  - WFA stated an intention to disable passive scanning via a proprietary build.
  - A proprietary build would not be reflective of real-use experience.
    - We strongly recommend against a test plan creating synthetic unrealistic conditions
    - Alternatively, if WFA chooses to perform test cases in synthetic unrealistic conditions, the proprietary builds shall be made available to LTE-U vendors, to verify issues that may arise from operation of WiFi nodes in unintended never-to-be-encountered conditions.

- Runs with unexpected KPIs
  - Unclear whether to classify a sample point with unusual KPIs as suffering from a measurement issue or an underlying baseline issue (e.g. misbehaving STA)

95%-ile Uplink one-way delays

(AP-A + AP-A baseline, -80 dBm AP-STA RSSI, Test Level 2)

Distribution of 95th percentile one way delay values across 100 iterations



Across 100 iterations, many iterations have STAs with <u>unexplainable</u> high one way delay values (shown here) and packet losses (shown in upcoming slides)

Unstable baseline makes comparison with LTEu – WiFi a statistical exercise and not a genuine co-existence requirement

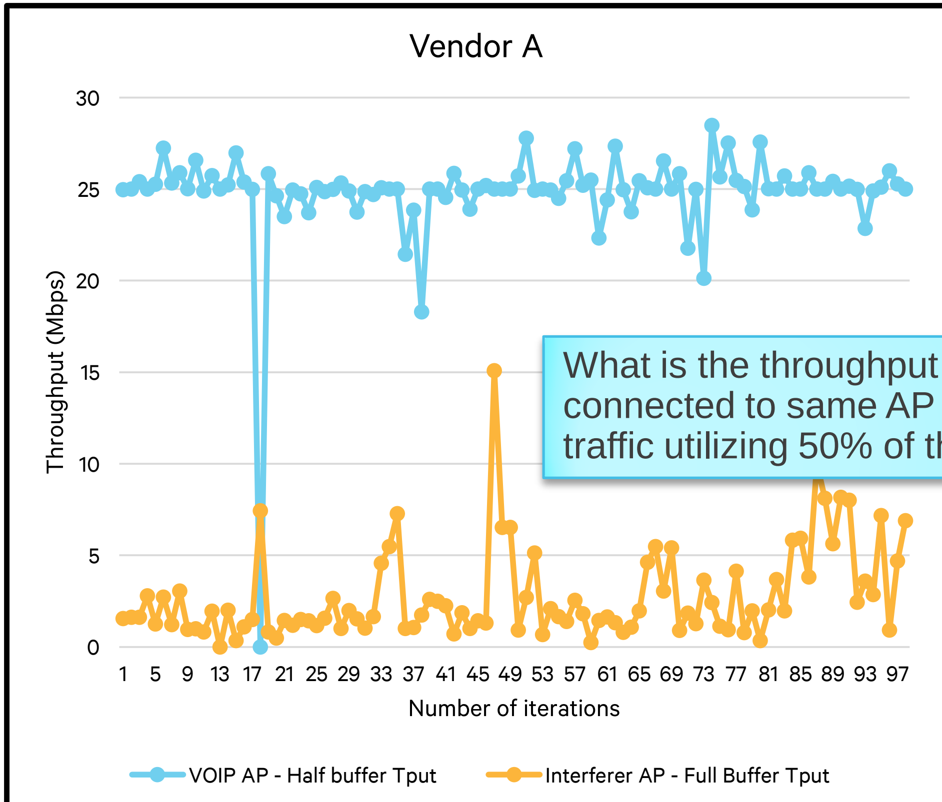
WiFi Throughput in the presence of VOIP flows

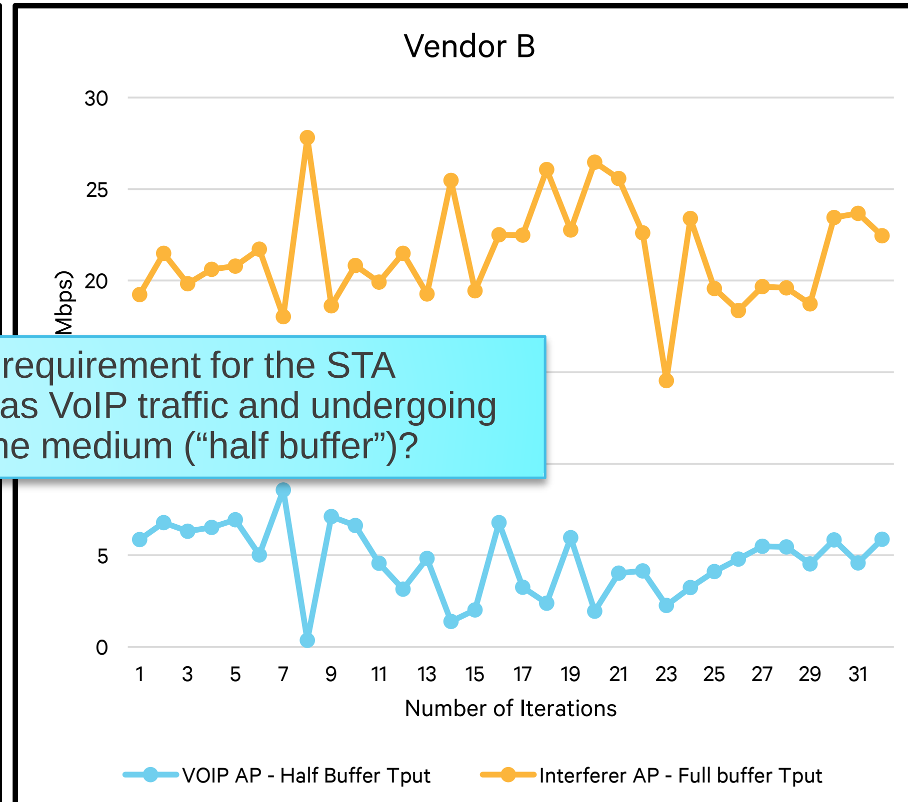
WiFi Throughput in the presence of VOIP flows

Half buffer – Same AP as VOIP flows, Offered load TCP 25Mbps

Full buffer – Interferer AP, Offered load TCP 50Mbps

(both graphs intra-vendor from AP perspective; vendors A and B are different)

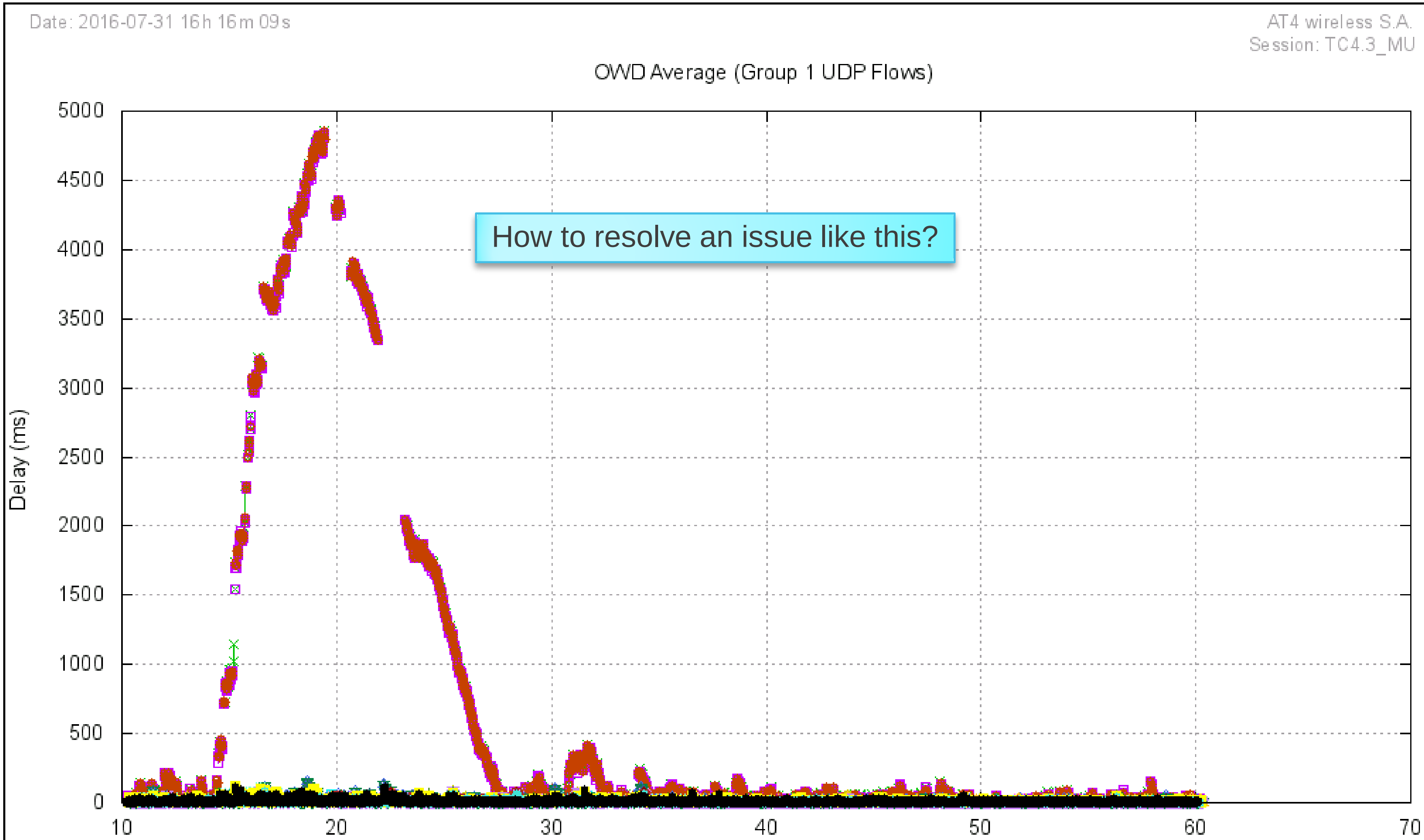




What is the throughput requirement for the STA connected to same AP as VoIP traffic and undergoing traffic utilizing 50% of the medium (“half buffer”)?

Impact of passive scanning behavior on VoWiFi flows

Unexpectedly high OWD … measurement issue? Underlying baseline issue?



Baseline Results – Test level 2 – Single Iteration

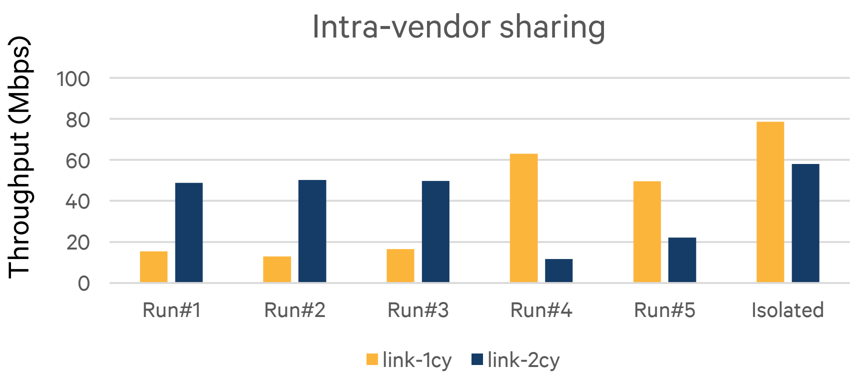
Flow	Type	Av. Throughput (Mbit/s)	Av. Delay (ms)	Peak Delay (ms)	Av. Jitter (ms)	Peak Jitter (ms)	Packet Loss (%)	Av. Consecutive Lost Packets	Max. Consecutive Lost Packets	Number of Consecutive Lost Packets
Flow1-VoIP-vendorA#bf	VoIP	0.069	167.319	1425.388	11.903	19.973	0	0	0	0
Flow1-VoIP-vendorA#br	VoIP	0.064	186.238	1731.104	16.636	36.889	5.075	1.5	41	82
Flow2-VoIP-vendorA#bf	VoIP	0.069	165.819	1413.663	11.019	19.971	0.201	1	1	5
Flow2-VoIP-vendorA#br	VoIP	0.064	186.182	1731.458	16.398	37.057	4.988	1.5	40	80
Flow3-VoIP-vendorA#bf	VoIP	0.069	165.224	1407.323	11.395	19.972	0	0	0	0
Flow3-VoIP-vendorA#br	VoIP	0.065	182.052	1684.935	16.99	38.141	4.462	1.5	40	71
Flow4-VoIP-vendorB#bf	VoIP	0.068	153.458	1292.841	11.223	19.992	0.762	1.6	7	12
Flow4-VoIP-vendorB#br	VoIP	0.067	77.715	623.604	10.357	20.789	2.525	1.7	8	38
Flow5-VoIP-vendorB#bf	VoIP	0.068	153.265	1288.241	11.056	19.989	1.003	1.3	7	19
Flow5-VoIP-vendorB#br	VoIP	0.067	80.267	634.333	11.309	20.125	2.886	1.6	13	46
Flow6-VoIP-vendorB#bf	VoIP	0.068	154.83	1302.163	11.659	21.935	0.602	1.9	7	8
Flow6-VoIP-vendorB#br	VoIP	0.067	79.279	631.244	10.79	20.485	3.006	1.6	13	46
Flow7-VoIP-vendorC#bf	VoIP	0.069	194.122	1658.706	12.113	19.972	0.12	1	1	3
Flow7-VoIP-vendorC#br	VoIP	0.068	117.264	1029.284	11.478	20.278	0.921	1.1	3	21
Flow8-VoIP-vendorC#bf	VoIP	0.069	193.875	1667.321	11.862	19.972	0.04	1	1	1
Flow8-VoIP-vendorC#br	VoIP	0.068	117.028	1022.995	11.738	20.424	0.881	1.2	4	19
Flow9-VoIP-vendorC#bf	VoIP	0.069	196.185	1666.093	12.68	19.984	0.12	1	1	3
Flow9-VoIP-vendorC#br	VoIP	0.068	119.173	1025.281	13.108	21.356	0.881	1.2	4	19
Flow10-VoIP-vendorD-DUT#bf	VoIP	0.069	185.657	1602.408	12.085	19.99	0.201	1	1	5
Flow10-VoIP-vendorD-DUT#br	VoIP	0.069	33.429	213.955	10.694	20.477	0.32	1.1	2	7
HB	TCP	4.824	1253.138	4766.264	16.453	507.528	N/A	N/A	N/A	N/A
FB	TCP	19.272	6078.403	11027.575	3.96	665.278	N/A	N/A	N/A	N/A

Appendix A

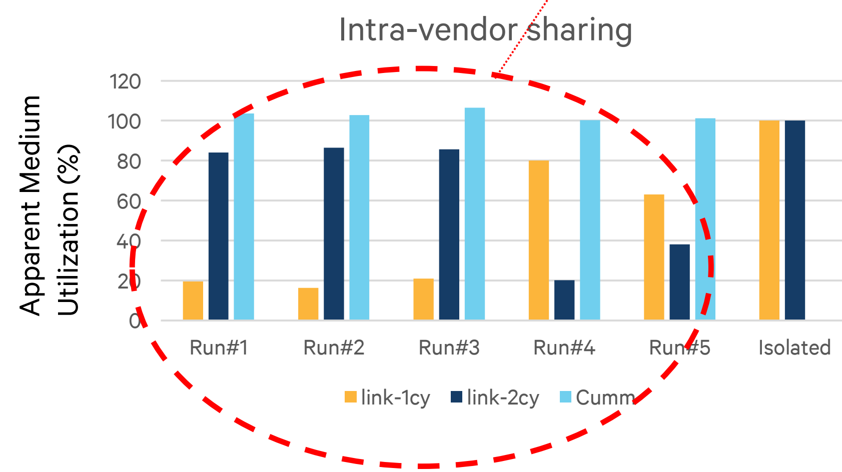
Other salient throughput sharing conditions

4.5: Illustration of WiFi + WiFi coexistence (intra-vendor)

- Intra-vendor coexistence shows non-ideal behavior
  - WiFi link1a: AP-C + STA_Y
  - WiFi link2a: AP-C + STA_Y



Unfair sharing



- Notes:
  - **Apparent medium utilization** of link X
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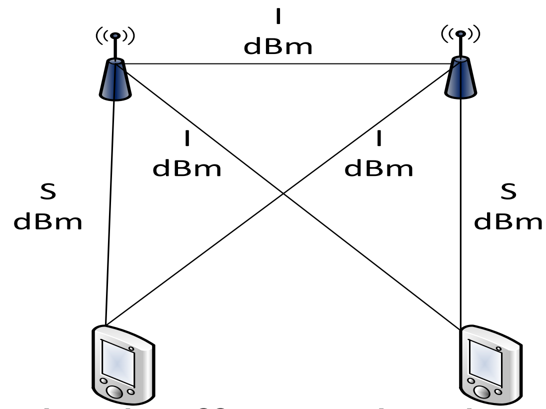
    - Intuitively measures the medium ratio used by link X when coexisting (ideally TDD-ing) with another link Y
  - **Cumulative apparent medium utilization** when links X and Y coexist:
    - = (Apparent medium utilization of link X) + (Apparent medium utilization of link Y)
  - AP-C is a model used in the WFA lab
  - STA_Y is a “latest-model” popular WiFi node
  - All test cases were run at test level-2, with AP-STA RSSI of -70 dBm

Appendix B

Example of unfair sharing behavior

Avalanche of RTS

- Architecture:



- In the run below, WiFi APs do not back off to each others' RTS, leading to an avalanche of RTS frames with overlapping NAVs and temporary stalling of DL traffic (STA CTSs are blocked by rival AP RTS NAVs).

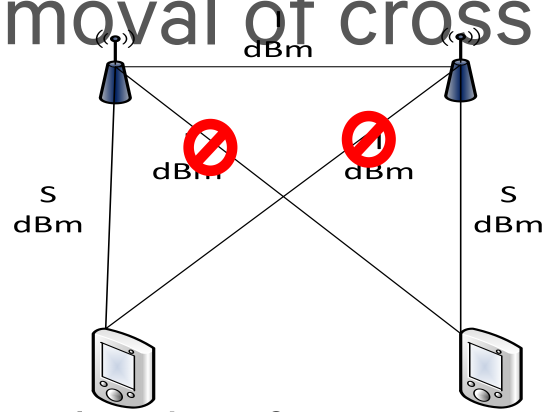
File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help

Apply a display filter ... <Ctrl-/>

No.	Time	Source	Destination	Protocol	Length	Duration	SSI Signal	Delta time	Info
43632	11.258556	[redacted] 10:0f:30 …	[redacted] 4a:98:88 …	802.11	63	5386	-42	0.000099	Request-to-send, Flags=........C
43633	11.258736	[redacted] 10:0f:30 …	[redacted] 4a:98:88 …	802.11	63	5386	-42	0.000180	Request-to-send, Flags=........C
43634	11.258928	[redacted] 10:0a:30 …	[redacted] 94:a4:de …	802.11	63	5498	-44	0.000192	Request-to-send, Flags=........C
43635	11.259142	[redacted] 10:0a:30 …	[redacted] 94:a4:de …	802.11	63	5498	-44	0.000214	Request-to-send, Flags=........C
43636	11.259463	[redacted] 10:0a:30 …	[redacted] 94:a4:de …	802.11	63	5498	-44	0.000321	Request-to-send, Flags=........C
43637	11.259676	[redacted] 10:0f:30 …	[redacted] 4a:98:88 …	802.11	63	5386	-42	0.000213	Request-to-send, Flags=........C
43638	11.260080	[redacted] 10:0f:30 …	[redacted] 4a:98:88 …	802.11	63	5386	-42	0.000404	Request-to-send, Flags=........C
43639	11.260290	[redacted] 10:0a:30 …	[redacted] 94:a4:de …	802.11	63	5498	-44	0.000210	Request-to-send, Flags=........C
43640	11.260676	[redacted] 10:0a:30 …	[redacted] 94:a4:de …	802.11	63	5498	-44	0.000386	Request-to-send, Flags=........C
43642	11.261234	[redacted] 10:0a:30 …	[redacted] 94:a4:de …	802.11	63	5498	-44	0.000178	Request-to-send, Flags=........C
43643	11.261463	[redacted] 10:0f:30 …	[redacted] 4a:98:88 …	802.11	63	5386	-42	0.000229	Request-to-send, Flags=........C
43644	11.261831	[redacted] 10:0f:30 …	[redacted] 4a:98:88 …	802.11	63	5386	-42	0.000368	Request-to-send, Flags=........C
43645	11.261921	[redacted] 10:0f:30 …	[redacted] 4a:98:88 …	802.11	63	5386	-43	0.000090	Request-to-send, Flags=........C
43646	11.262093	[redacted] 10:0f:30 …	[redacted] 4a:98:88 …	802.11	63	5386	-42	0.000172	Request-to-send, Flags=........C
43647	11.262313	[redacted] 10:0a:30 …	[redacted] 94:a4:de …	802.11	63	5498	-44	0.000220	Request-to-send, Flags=........C

Avalanche of RTS: removal of cross links

- Architecture:



- Removing cross links stops the avalanche of RTSs; since STAs are not exposed anymore to overlapping NAVs, they have a chance to CTS their own AP’s RTS

File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help

Apply a display filter … <Ctrl-/>

No.	Time	Source	Destination	Protocol	Length	Sequence number	Duration	Delta time	SSI Signal	Info
1572	0.405897	172.20.161.179	172.20.161.142	UDP	1564	2555	48	0.000098	0	43600 → 9000 Len=1450
1573	0.405998	172.20.161.179	172.20.161.142	UDP	1564	2556	48	0.000101	0	43600 → 9000 Len=1450
1574	0.406108	172.20.161.179	172.20.161.142	UDP	1564	2557	48	0.000110	0	43600 → 9000 Len=1450
1575	0.406208	172.20.161.179	172.20.161.142	UDP	1564	2558	48	0.000100	0	43600 → 9000 Len=1450
1576	0.406316	172.20.161.179	172.20.161.142	UDP	1564	2559	48	0.000108	0	43600 → 9000 Len=1450
1577	0.406429	172.20.161.179	172.20.161.142	UDP	1564	2560	48	0.000113	0	43600 → 9000 Len=1450
1578	0.406521	172.20.161.179	172.20.161.142	UDP	1564	2561	48	0.000092	0	43600 → 9000 Len=1450
1579	0.407757	[redacted]_10:0a:30	Broadcast	802.11	264	2214	0	0.001236	-42	Beacon frame, SN=2214, F
1580	0.407867	[redacted]_10:0f:30 (94:b…	[redacted]4a:98:88 (…	802.11	63		5338	0.000110	-42	Request-to-send, Flags=.
1581	0.408137	172.20.161.179	172.20.161.232	UDP	1564	457	48	0.000270	0	52555 → 9000 Len=1450
1582	0.408264	172.20.161.179	172.20.161.232	UDP	1564	476	48	0.000127	0	52555 → 9000 Len=1450
1583	0.408424	172.20.161.179	172.20.161.232	UDP	1564	477	48	0.000160	0	52555 → 9000 Len=1450
1584	0.408551	172.20.161.179	172.20.161.232	UDP	1564	478	48	0.000127	0	52555 → 9000 Len=1450
1585	0.408686	172.20.161.179	172.20.161.232	UDP	1564	488	48	0.000135	0	52555 → 9000 Len=1450
1586	0.408835	172.20.161.179	172.20.161.232	UDP	1564	489	48	0.000149	0	52555 → 9000 Len=1450
1587	0.408969	172.20.161.179	172.20.161.232	UDP	1564	490	48	0.000134	0	52555 → 9000 Len=1450
1588	0.409122	172.20.161.179	172.20.161.232	UDP	1564	491	48	0.000153	0	52555 → 9000 Len=1450
1589	0.409399	172.20.161.179	172.20.161.232	UDP	1564	493	48	0.000277	0	52555 → 9000 Len=1450
1590	0.409531	172.20.161.179	172.20.161.232	UDP	1564	494	48	0.000132	0	52555 → 9000 Len=1450
1591	0.409675	172.20.161.179	172.20.161.232	UDP	1564	495	48	0.000144	0	52555 → 9000 Len=1450
1592	0.409808	172.20.161.179	172.20.161.232	UDP	1564	496	48	0.000133	0	52555 → 9000 Len=1450
1593	0.409947	172.20.161.179	172.20.161.232	UDP	1564	497	48	0.000139	0	52555 → 9000 Len=1450